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Contrast Sensitivity in Army Aviator Candidates: Cyclopegia Effects and Population Norms

By

Isaac Behar
William G. Bachman

Sensory Research Division

and

Walter Egenmaier

Lyster U.S. Army Community Hospital

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United States Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36362-5292

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This study was designed to provide information regarding three aspects of contrast sensitivity testing of aviator candidates: 1. To determine whether contrast sensitivity functions (CSFs) obtained with the VISTECH Visual Contrast Test System (VCTS) are affected by ocular cycloplegia; 2. Since Army aviator candidates differ from the general population by being more highly selected with respect to visual and refractive status, and more homogeneous in age and in an age bracket when vision is optimal, a second purpose was to obtain a large normative sample of CSFs for establishing future contrast sensitivity standards for this population; and 3. To determine whether the VCTS provides useful CSFs under clinical screening conditions in a timely and simple manner. Contrast sensitivity thresholds were obtained at 5 spatial frequencies from 106 aviator candidates, prior to and following the administration of a cycloplegic. Contrast sensitivity functions obtained under cycloplegia were reduced about 20 percent. The CSFs of the aviator candidates are much superior than the general population norms. The VCTS provides useful CSFs under military screening conditions.

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Introduction

The determination of the visual contrast sensitivity function (CSF) has been identified as a new or emergent technique that offers exciting potential for a more complete assessment of vision in clinical, industrial, and military settings (Committee on Vision, 1985). The ability to detect small individual differences in spatial vision may have a significant application in the military aviation environment. For example, evidence has been presented that components of the CSF were better than conventional, high contrast visual acuity for predicting pilot performance in detecting small, low contrast targets in aircraft simulators (Ginsburg et al., 1982), in the laboratory (Stager and Hameluck, 1986), and in the field (Ginsburg, Easterly, and Evans, 1983).

Initial selection of candidates for flying duty requires that a cycloplegic refraction be accomplished on the individuals (AR 40-501). Bachman and Behar (1987) recently have shown there is a small, but significant loss of sensitivity under cycloplegic conditions. That study used a small number of observers (N=12), and testing was done with a sophisticated contrast sensitivity apparatus (Nicolet CS-2000*) that is microcomputer controlled and generates test patterns on a video display. A test system of this type would not be appropriate for clinical screening in conjunction with the qualifying flight physical as it is costly, requires calibration and maintenance, administration is too time consuming (about 30 min), and is rather complex. Recently, a wall chart Vision Contrast Test System (VCTS)* was introduced (Ginsburg, 1984) that produces CSFs similar to those obtained by researchers using video based systems (Ginsburg and Evans, 1985; Corwin and Richman, 1986). The VCTS appears to meet the criteria for a military screening system in that it be quick and easy to administer and score, and is inexpensive.

This study was designed to provide information regarding three aspects of contrast sensitivity testing of aviator candidates: 1. To determine whether CSFs obtained with the VCTS also are affected by ocular cycloplegia; 2. To obtain a large normative sample of CSFs for establishing future contrast sensitivity standards for this population, since Army aviator candidates differ from the general population by being more highly selected with respect to visual and refractive status, and more homogeneous in age and in an age bracket when vision is optimal; 3. To gain experience with the VCTS within the context of military clinical screening conditions.

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* See Appendix A

Method

Subjects (Ss)

One-hundred and six candidates for rotary-wing aviator training, including four women, volunteered as Ss; half were commissioned officers and half were warrant officer candidates (WOCs). The median ages were 23.3 and 23.9 years, respectively All WOCs were required to pass a Class 1 flight physical, while the commissioned officers were required to pass a Class 1A flight physical. One S failed to meet the hearing standards so was not available for postcycloplegia testing.

Procedure

Testing was conducted in conjunction with the qualifying flight physical, with groups of approximately 25 to 30 candidates participating on a given day. Subjects first received contrast sensitivity testing (see below) under normal or undilated conditions. Cycloplegia then was induced using 1 percent cyclopentolate (Cyclogel*) which is a parasympatholytic drug administered topically to the eye. Each subject received one drop in each eye followed by a second drop after 5 minutes. A minimum of 30 minutes was allowed after administration for maximum effect of the drug. Cyclopentolate blocks the responses of the sphincter muscle of the iris and the accommodative muscle of the ciliary body to cholinergic stimulation, producing pupillary dilation (mydriasis) and paralysis of accommodation (cycloplegia). Subjects then were refracted at the standard examination distance of 20 feet, using both subjective refraction and static retinoscopy to determine spherical and cylindrical components. Optical corrections, to include plano results, then were incorporated into a standard trial frame. Since refractions were done at 20 feet, while CSF testing was done at 10 feet, +0.25 diopter of sphere power was added to each correction to compensate for the reduced viewing distance. Contrast sensitivity testing then was accomplished with the trial frame in place under dilated conditions.

Contrast sensitivity thresholds were obtained using Vistech VCTS 6500 Charts. Testing was performed at the standard viewing distance of 10 feet and at the recommended illumination level (as measured with a Vistech light meter). The VCTS charts permit threshold determination at five spatial frequencies: 1.5, 3, 6, 12, and 18 cycles per degree (cpd); these spatial frequencies are labeled A through E on the Vistech charts. Stimuli consist of circular patches of sinusoidal gratings arrayed in rows and columns. The gratings in each row are of a single spatial frequency, 1.5 cpd in the first row, 3 cpd in the second, etc. Each leftmost patch is of relatively high contrast and contrast

decreases progressively by approximately 0.1 log unit in each of the remaining eight patches in the row. The S's task was to identify the orientation of each grating, which could be vertical, or tilted plus or minus 15 degrees from the vertical. Subjects' responses to each patch in a row were recorded and they were encouraged to guess, if necessary. The contrast of the last correctly identified patch before the first error was scored as the threshold for that spatial frequency, unless three successive correct responses were made immediately following the first error, in which case that error was considered a misreporting or recording error and was ignored. This occurred very infrequently.

Thresholds were obtained first with binocular viewing, then with the left eye only (for half the Ss), followed by testing with the right eye. For the other Ss, the order of monocular testing was reversed. For many Ss, contrast sensitivity was lower for the monocular condition tested second, suggesting that those Ss put pressure on the occluded eye or kept it closed behind the occluder. Because of this possible artifact, only the data for the first monocular condition tested will be reported. In addition, through experimental error, 14 Ss were not tested with the same eye in the first monocular conditions prior to and following cyclopentolate administration; therefore, this comparison is based on a reduced N of 91.

Results

Cycloplegia effects

The binocular mean contrast sensitivity for each spatial frequency obtained prior to and following administration of cyclopentolate for the entire group of Ss (N=105) is presented graphically in Figure 1. It may be seen that contrast sensitivity is reduced at all spatial frequencies following cyclopentolate administration; this effect is highly significant statistically ($F=169.41$, $df=1,104$, $p<.0001$). The interaction of cycloplegia and spatial frequency is not significant. The overall ratio of cycloplegic to precycloplegic sensitivity was 0.79, hence, under cycloplegic conditions, the mean contrast sensitivity was reduced by 21 percent. Figure 2 portrays the corresponding results for the first tested monocular conditions (based on the reduced sample size of 91). Again, the cycloplegia effect is highly significant ($F=84.54$, $df=1,90$, $p<.0001$), but, in addition, the interaction of cycloplegia and spatial frequency is significant ($F=7.66$, $df=4,360$, $p<.0001$). The mean ratio of cycloplegic to precycloplegic sensitivity is 0.76, while the ratios for the individual spatial frequencies are given in Table 1.

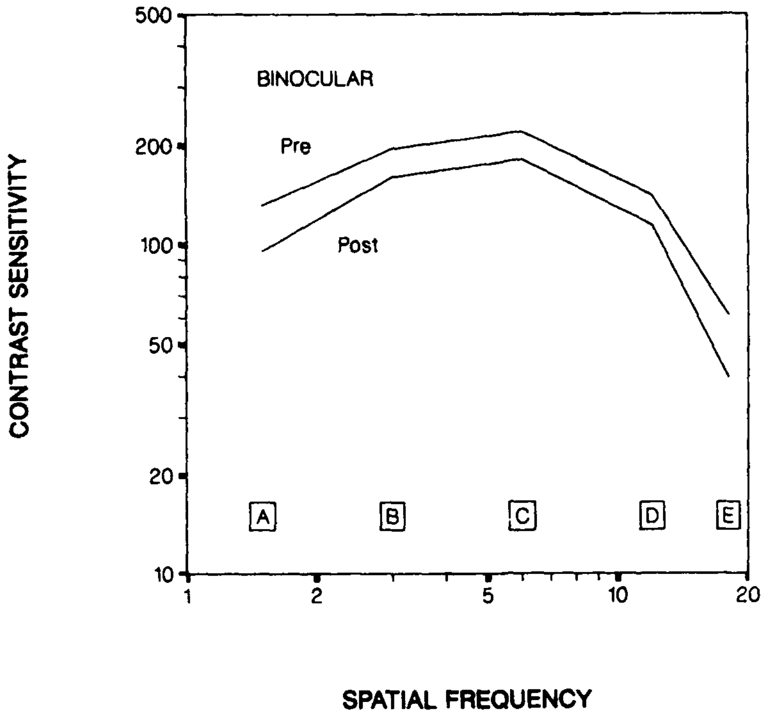

Figure 1. Mean contrast sensitivity functions obtained under binocular viewing measured before and after administration of cyclopentolate (N=105).

Binocular-monocular differences

The mean contrast sensitivity under normal (undilated) viewing conditions is graphically presented in Figure 3 separately for the binocular and first monocular conditions. It may be seen that contrast sensitivity was superior when viewing was binocular; the difference between viewing conditions was highly significant ($F=149.30$, $df=1,104$, $p<.0001$). The ratio of binocular to monocular sensitivity is taken as an indication of binocular summation (Campbell and Green, 1965), and in this study was 1.27 overall, but varied as a function of spatial frequency as shown in Table 2. The interaction between viewing condition and spatial frequency was significant ($F=4.78$, $df=4,416$, $p<.0009$). The difference between viewing conditions cannot be accounted for by inferior performance, for example, with the left eye. Subjects for whom the left eye was tested first did equally well as Ss for whom the right eye was tested first ($F=1.67$, $df=1,104$, $p=.1990$).

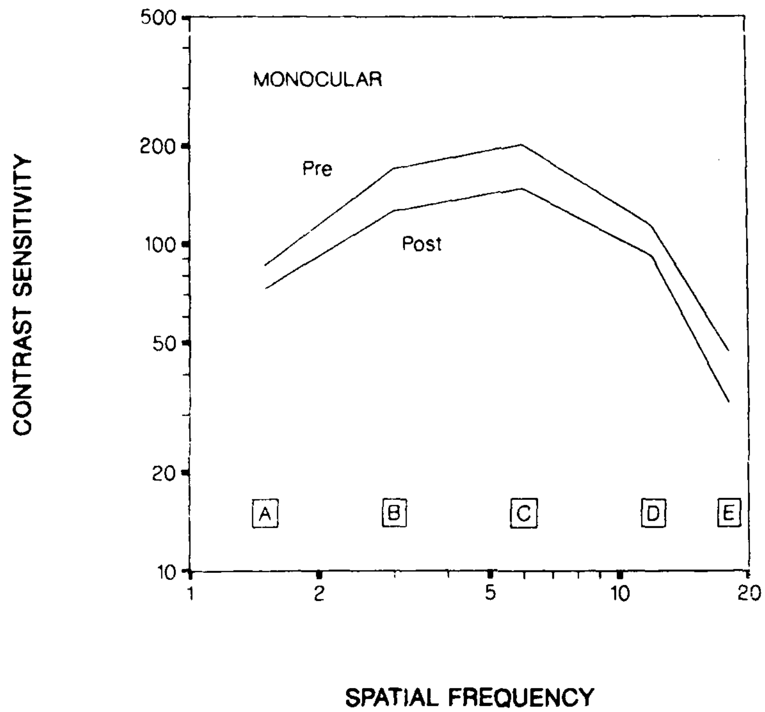

Figure 2. Mean contrast sensitivity functions obtained under monocular viewing measured before and after administration of cyclopentolate (N=105).

Table 1.

Ratios of cycloplegic to precycloplegic contrast sensitivity.

Spatial frequency

	1.5	3	6	12	18
Ratio	0.85	0.74	0.73	0.81	0.70

Aviator candidate VCTS norms

Data analyses for the contrast sensitivity norms followed those of Corwin and Richman (1986). Histograms of raw scores obtained from all 106 aviator candidates prior to cyclopentolate administration for each spatial frequency were tabulated, from which medians, quartiles, and 10th and 90th percentiles were calculated. These scores then were converted to absolute contrast

using the Value Keys of the 1986 Vistech evaluation forms, interpolating when necessary.

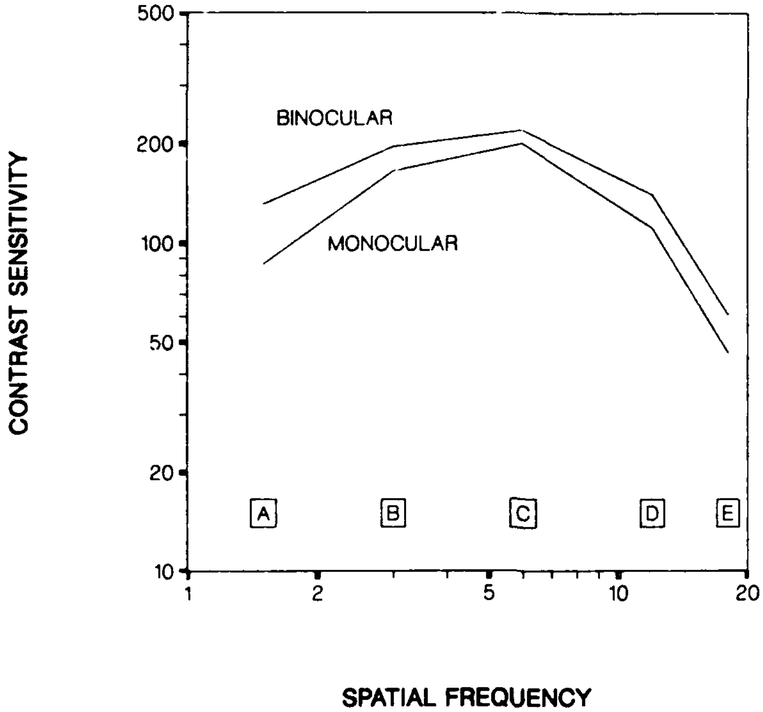

Figure 3. Mean contrast sensitivity functions obtained under binocular and monocular viewing measured before administration of cyclopentolate (N=106).

Figure 4 presents the contrast sensitivity functions for the 90th, 75th, 50th, 25th, and 10th percentile aviator candidate obtained with binocular viewing. Also plotted in this figure are the contrast values for selected stimulus patches. For example, looking at the 1.5 cycle per degree spatial frequency (labeled Row A on the VCTS charts), in order to achieve the level of performance of the 10th percentile observer, one would need to correctly identify the grating orientation of stimulus patch 6 (i.e., have a contrast sensitivity of about 70). Figure 5 displays the corresponding functions obtained with monocular viewing. Table 3 summarizes the values of the lowest stimulus patches that need to be correctly reported in order to meet or exceed the contrast sensitivity of the 10th percentile aviator candidate.

Table 2.

Ratios of binocular to monocular contrast sensitivity.

	Spatial frequency				
	1.5	3	6	12	18
Ratio	1.52	1.19	1.10	1.26	1.30

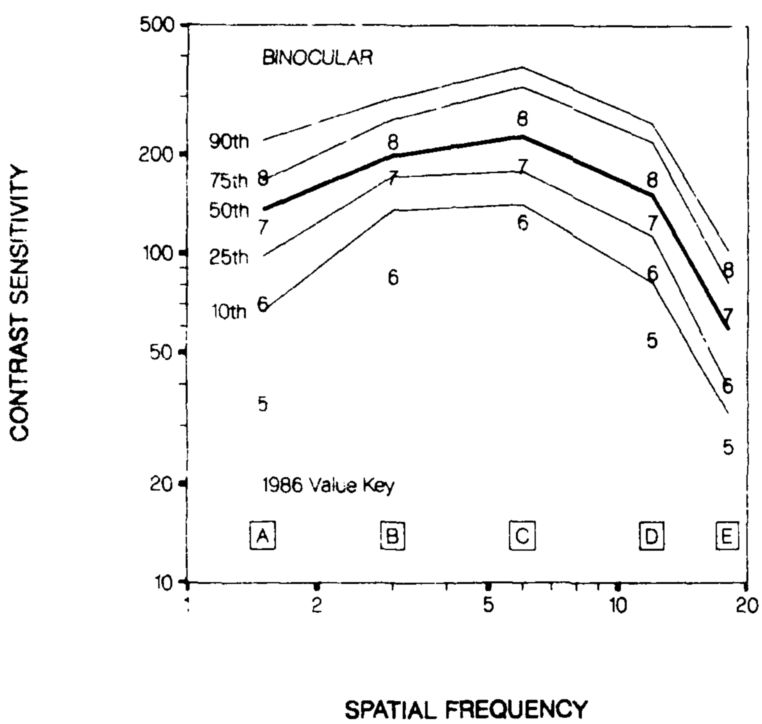

Figure 4. Contrast sensitivity fuctions for the 90th, 75th, 50th, 25th, and 10th percentile aviator candidates obtained with binocular viewing (N=106).

Comparison with other VCTS norms

The standardization norms that accompany the VCTS charts were obtained from a sample of the general population wearing habitual eye correction and ranging in age from 10 to 70; and were obtained with binocular viewing. In comparison with that group, as seen in Figure 6, the aviator candidates of the present study exhibited

considerably higher sensitivity at all spatial frequencies. In this figure, the gray area represents the middle 90 percent of general population observers (i.e., 5th to 95th percentile), and the bold Xs and Ls are the 10th and 50th percentiles of the present study. The contrast sensitivity of the median aviator candidate equals or exceeds that of the 95th percentile general population observer, and the contrast sensitivity of the 10th percentile aviator candidate equals or exceeds that of the median general population observer.

Monocular VCTS scores were published by Corwin and Richman (1986) for a sample of second-year optometry students wearing their best refractive correction. Their mean age was 24.7 years which is similar to that of the aviator candidates. Table 4 compares the present results obtained with monocular viewing with those norms. The median VCTS scores of the two groups are very similar, as are the measures of dispersion.

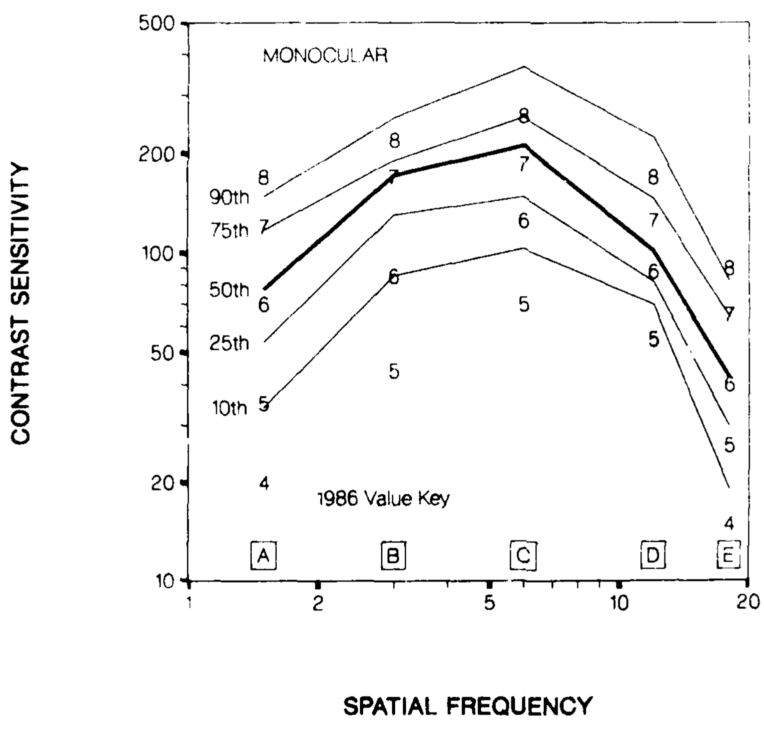

Figure 5. Contrast sensitivity functions for the 90th, 75th, 50th, 25th, and 10th percentile aviator candiates obtained with monocular viewing (N=106).

Table 3.

VCTS stimulus patch needed to match or exceed the contrast sensitivity of the 10th percentile aviator candidate.

	Spatial frequency				
	1.5	3	6	12	18
Binocular	6	7	7	6	6
Monocular	5	6	6	6	5

Discussion

Cycloplegia effects

The first purpose of this study was to determine whether CSFs obtained with the VCTS are affected by ocular cycloplegia. The results indicate the VCTS is in fact sensitive to the introduction of a cycloplegic; a more than 20 percent reduction in sensitivity was found under either binocular or monocular conditions after cycloplegia. Since Ss wore optical corrections for the test distance, this can be attributed to a reduction in retinal image quality due to aberration (Bachman and Behar, 1987).

Aviator candidate VCTS norms

The second purpose of this study was to obtain a large normative sample of CSFs for establishing future contrast sensitivity standards for aviator candidates. These standards would serve either of two functions, selection for medical fitness *per se* or selection for special occupational requirements. The Medical Services Standards of Medical Fitness (AR 40-501) already includes a standard for spatial vision based upon the traditional measure of high contrast acuity. This measure has advantages such as historical success and universal acceptance. Deficits observed in visual acuity immediately alert the practitioner to the presence of an ametropia or other ophthalmological or neurological disorder, and determine the individual's fitness for occupations requiring detail vision.

While visual contrast sensitivity also reflects an aspect of spatial vision, only performance at the higher spatial frequencies is related to visual acuity (Kinney and Luria, 1980); contrast sensitivity for the low and medium spatial frequencies appears to be processed by different neural mechanisms (Regan, 1988). Unlike

Table 4.

Group median scores and interquartile ranges (in parentheses) obtained in the present study, compared with those obtained by Corwin and Richman (1986).

	Spatial frequency				
	1.5	3	6	12	18
Aviator candidates	6.20 (1.34)	7.04 (0.84)	7.39 (1.54)	6.42 (1.67)	6.11 (1.66)
Optometry students	6.50 (1.16)	7.14 (1.14)	6.92 (1.16)	6.50 (1.78)	6.00 (1.44)

visual acuity, which is represented by a single value (e.g., 20/20), contrast sensitivity usually is measured at several spatial frequencies and the overall result is plotted as a contrast sensitivity function. There is no agreement on a procedure for quantifying an average contrast sensitivity value, nor is there a rational basis for doing so, especially since the overall shape of the CSF may be more diagnostic of a given disorder than the absolute contrast sensitivity at any frequency.

If contrast sensitivity testing was given as a matter of routine, deficits observed in the CSF, whether at specific spatial frequencies or overall, "would allow the practitioner to find the first evidence of eye diseases or neurological disorders earlier than with conventional tests or procedures, and occasionally may facilitate differential diagnosis of eye problems" (Woo and Dalhsack, 1986). For this purpose, the CSF norms obtained in this study may represent a more suitable sample than the general population norms, especially for presumed healthy, young military men. For lack of a more appropriate criterion for establishing medical fitness standards for contrast sensitivity, the use of the 10th percentile values is our arbitrary recommendation for defining a "suspicious zone." If a test of contrast sensitivity routinely is administered early, a longitudinal study could determine whether poor performers - those individuals whose contrast sensitivity at any spatial frequency is below the 10th percentile of our aviator candidate sample, even though well within the general population norms - are more likely to manifest vision-related disorders.

Contrast sensitivity also has been proposed as a criterion for selecting individuals for designated military occupations (Ginsburg, 1981), for example, those requiring superior target acquisition skills. However, the early apparent success by Ginsburg and his collaborators (cited above) in relating pilot contrast sensitivity scores with target acquisition performance

has not been replicated by other researchers (Kruk and Regan, 1983; Kruk et al., 1983; O'Neal and Miller, 1987; Irvin et al., 1988). A current Army study is investigating the relationship between laboratory measures of vision, including contrast sensitivity, and target acquisition performance of infantry gunners (Levine, 1987). Needless to say, because of the inconsistent outcomes of different studies and the very limited sampling of MOS-relevant tasks, it would be premature and unfair to suggest contrast sensitivity standards be used for military occupational selection at the present time.

Measurement of contrast sensitivity

The final purpose of this study was to gain some experience with the VCTS within the context of military clinical screening conditions in which large groups receive physical assessment. Among the criteria of a useful test is that it be simple to administer and score. Training of technicians in the use of the VCTS is not as straight-forward as letter charts, but was accomplished in about an hour. The administration and scoring of the test were found to be acceptably simple and quick (about 3 minutes for each test condition), and from the viewpoint of the examinees the test was not too difficult or tedious. If "blank" responses are not allowed, the VCTS is a three-alternative forced-choice test which is relatively free of subjective criterion shifts (Vaegan and Halliday, 1982; Higgins et al., 1984).

Performance on the test has been found to improve slightly but significantly on retest (Woo and Bohnsack, 1986). Thus, if contrast sensitivity testing were to be included in the flight physical visual test battery, we recommend that it first be accomplished with binocular viewing to familiarize the examinee with this nontraditional test and to minimize practice effects during monocular testing.

Although the VCTS charts are in wide use, alternative test charts for low-contrast spatial vision exist, including the Regan Low-contrast Letter Acuity Charts (Regan and Neima, 1983), the Pelli-Robson Letter Sensitivity Chart (Pelli, Robson, and Wilkins, 1988), and the Bailey-Lovie chart. Letter charts for measuring contrast sensitivity have the advantage that naming letters is easier than identifying grating orientation (and not subject to left-right confusions). Performance on letter charts has been reported to have higher test-retest reliability than does the VCTS and to be less susceptible to subject errors (Rubin, 1988). As these are relatively new tests, there exists no standardized performance on any letter contrast sensitivity test for any military population.

Conclusions

The contrast sensitivity function is a technique that offers a more complete assessment of visual function than does the traditional determination of visual acuity. It is recommended that a test of contrast sensitivity be incorporated into the standard flight physical.

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Appendix A

Alcon Laboratories, Inc.
P. O. Box 1959
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Nicolet Biomedical Division
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University of Illinois-
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ISSM, USC
Los Angeles, CA 90089-0021

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Fort Rucker, AL 36362

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